

# Decisive search for a diquark-antidiquark meson with hidden strangeness

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## Abstract

Diquark-antidiquark states are expected to exist as a natural complement of mesons and baryons. Although they were predicted long ago, and some candidates were found experimentally, none has, as yet, been reliably identified. We suggest that the search for the so-called  $C(1480)$ -meson in reactions such as photoproduction  $\gamma N \rightarrow \phi \pi N$  and  $KN \rightarrow \phi \pi \Lambda$  should provide a decisive way to settle this issue. Estimates of the cross sections are given using present experimental information on the C-meson and assuming its diquark-antidiquark structure. Sizable cross sections are predicted (of the order of  $0.1 \mu\text{b}$  for photoproduction and of the order of  $0.1 \text{ mb}$  for  $KN$  at the maximum with an insignificant background). Failure to find this kind of signal would imply that the C-meson is *not* a diquark-antidiquark state.

1. *Historical perspective:* within the quark model, ordinary mesons are  $q-\bar{q}$  states *i.e.* color singlets made of (spin 1/2) elementary color  $\{3\} - \{\bar{3}\}$  called quarks. Very soon after the quark model was proposed, it was also suggested [1] that four quark or exotic states made of diquark-antidiquark pairs should exist. This is in keeping with the notion that the color singlet  $qqq$  baryons states can also, to some extent and in some circumstances, be viewed as objects composed of a quark-diquark systems. In both cases (exotic mesons and baryons), what makes the parallelism with ordinary mesons stringent, is that the diquarks act again as (spin 0 or 1) color antitriplets (recall that a two-quark or diquark system can be decomposed as an antitriplet plus a sextet or  $3 \otimes 3 = \bar{3} \oplus 6$ ).

While most authors would consider diquarks as useful and simple ways of describing complicated non-perturbative phenomena in some intermediate energy domain, they do indeed show some elementarity. For an updated review on diquarks, see Anselmino et al. [2], where an extended literature to earlier references can also be found.

2. *Decay channels:*  $q - \bar{q}$  mesons decay mostly into other mesons by creating new  $q - \bar{q}$  pairs from the vacuum. The same mechanism explains also the decay of baryons into baryons plus mesons. Such a mechanism can also provide the decay of a  $(\bar{q}\bar{q}) - (qq)$  state to baryon-antibaryon (plus mesons) if its mass is above the production threshold. However many states are predicted below the threshold, and may therefore only decay into mesons. The new specific mechanism which must be at work in this case is rearrangement of the quarks from  $qq$  and  $\bar{q}\bar{q}$  into two  $q\bar{q}$  states. In this case, however, as in so many other hunts for exotics, the essential problem is to find a signature which provides a reliable identification .

It was suggested long ago [3] that a promising signature could be associated to a diquark-antidiquark state with hidden strangeness,  $(\bar{q}\bar{s}) - (qs)$ . As a result of quark rearrangement, such a state could only decay, presumably with about equal probabilities, either into  $K\bar{K}$  or to  $\phi\pi$  (additional pions are of course possible). In particular, the latter channel is expected to be suppressed by at least two orders of magnitude by the OZI rule, if the parent meson has a  $q - \bar{q}$  or  $s - \bar{s}$  structure instead of the diquark-antidiquark one. So, the observation of a state, decaying into  $\phi\pi$  with *non-suppressed branching ratio for this channel*, would indeed be a reliable signature of its  $(\bar{q}\bar{s}) - (qs)$  structure.

3. *Experimental situation:* A candidate for such a state (named C(1480) in the literature) was found in Serpukhov [4] in the reaction  $\pi^- p \rightarrow \phi\pi n$  with a 32.5 GeV/c pion beam and with a cross section

$$\sigma(\pi^- p \rightarrow Cn)BR(C \rightarrow \phi\pi^0) = 40 \pm 15nb. \quad (1)$$

Unfortunately, in this experiment, only the total width,  $\Gamma_{tot} = 130 \pm 60 \text{ MeV}$  was

established. The presence of the unknown vertex  $C \rightarrow \pi\pi$  in this process prevents any possibility to fix the branching ratio of the  $\phi\pi$  channel. As a consequence, the interpretation of this state is still questionable.

In addition, this state  $C(1480)$  was searched for by the ASTERIX collaboration in antiproton annihilation at rest,  $\bar{p}p \rightarrow \phi\pi\pi$ . No signal was found, and only an upper limit was put on the cross section of C-meson production [5]. However, in a situation when the production cross section cannot be reliably predicted (which is also the case for the Serpukhov experiment) there could be no contradiction between the two experiments.

The only way to settle the issue is to search for the state under consideration in processes with predictable cross section; this would also provide the possibility to measure the partial width for the decay into  $\phi\pi$ .

4. *Photoproduction of  $C(1480)$* : In this paper we suggest to search for the state  $C(1480)$  in the reactions  $\gamma N \rightarrow \phi\pi N$ . The diagram, corresponding to photoproduction is shown in fig.1. We use here the vector dominance model, and assume pion exchange. According to previous consideration, the partial width  $C \rightarrow \phi\pi$  should be roughly a half of the total width, if the C meson is a  $(\bar{q}s) - (qs)$  state. In such a case all vertices of this diagram are known, and the cross section can be reliably predicted as,

$$\frac{d\sigma}{dt dM^2} = \frac{\alpha}{f_\phi^2} \frac{g_{\pi NN}^2}{4\pi} \frac{-t}{(m_\pi^2 - t)^2} \frac{M^2}{s^2} \sigma_{el}^{\pi\phi}(M) e^{R^2 t} \quad (2)$$

The  $\pi\phi$  elastic scattering cross section at the c.m. energy  $M$ ,  $\sigma_{el}^{\pi\phi}(M)$  has two components,

$$\sigma_{el}^{\pi\phi}(M) = \sigma_P^{\pi\phi}(M) + \sigma_C^{\pi\phi}(M) \quad (3)$$

where  $\sigma_P^{\pi\phi}$  is a non-resonant background provided by Pomeron exchange (other Reggeon exchanges are strongly suppressed by the OZI rule and will be ignored). This contribution can easily be estimated using the additive quark model with a reliability which is largely sufficient for our present purposes. For the total cross section we find  $\sigma_{tot}^{\pi\phi} \approx 8$  mb. The same estimate follows from VDM analyses of data on  $\phi$  photoproduction on nuclei [6]. Then, we use  $\sigma_P^{\pi\phi} = (\sigma_{tot}^{\pi\phi})^2 / 16\pi B_{el}^{\pi\phi}$  to estimate the elastic cross section. Using  $B_{el}^{\pi\phi} \approx 6 \text{ GeV}^{-2}$ , we get as an energy-independent background  $\sigma_P^{\pi\phi}(M) \approx 0.6$  mb.

For the resonant contribution coming from the  $C(1480)$  meson to  $\sigma_{el}^{\pi\phi}(M)$  we use the following form

$$\sigma_C^{\pi\phi}(M) = 4\pi \frac{k_f}{k_i k_0^2} \left[ 1 + 4 \frac{(M - M_C)^2}{\Gamma_{tot}^2} \right] \quad (4)$$

where we have taken  $\Gamma_{\phi\pi} \approx 1/2\Gamma_{tot}$ .  $k_i, k_f$  are the  $\phi - \pi$  c.m. momenta in initial and final states respectively. The former is calculated for massless  $\phi$  and  $\pi$ . For  $k_0$  we take  $k_0 = k_f(M = M_C)$ . This combination of momenta takes into account the threshold behavior of the partial width  $\Gamma_{\phi\pi}$  and corrections to the flux factor for the off-mass-shellness of  $\phi$  and  $\pi$  in the initial state. As for the other parameters appearing in (4), we use standard values:  $f_\phi^2/4\pi \approx 14$ ;  $g_{\pi NN}^2/4\pi \approx 15$ ;  $R^2 \approx 3.3$  GeV<sup>-2</sup> [6,7].

We integrate (2) from  $t_{min}$  to  $t_{max}$ , which are the values of the minimal and of the maximal 4-momentum transfer squared in  $\phi - \pi$  scattering, taking into account that the particles are off-shell in the initial state. This provides a correct energy behavior of the cross section at threshold.

The result for the energy dependence of the cross section of C-meson photoproduction is shown in fig.2 versus photon energy. The cross section shows a maximum at  $E_\gamma \approx 4.5$  GeV which results from the interplay of the near threshold growth and of the decrease with energy as  $s^{-2}$  of the pion-exchange contribution.

The  $\phi\pi$  mass distribution is shown in fig.3 at  $E_\gamma = 4$  GeV. In spite of the phase factor  $M^2$  in (2) the  $M^2$ -distribution looks pretty symmetrical as a results of the compensating threshold behavior at large  $M$ . The background of the Pomeron-exchange elastic cross section,  $\sigma_P^{\phi\pi}$ , is also included but its effect, however, proves to be negligibly small.

Our result deserves some comment, given that it corresponds to the somewhat surprisingly large cross section of about 100 nb whereas one would naively have expected a strong suppression due to the OZI rule had the C-meson been just an ordinary meson. It is just the alleged diquark-antidiquark structure of the C-meson which removes the suppression. Note that the cross section predicted at 32 GeV,  $\approx 6$  nb is not so much less then that observed in [4] for C-production by pions, 40 nb whereas, naively, one would expect a suppression by more than three orders of magnitude from the factor  $4\pi\alpha/f_\phi^2$  in (2). Such a small cross section of hadroproduction means strong suppression, by more than two order of magnitude, of the  $C \rightarrow \pi\pi$  decay, if  $C$  is really a diquark-antidiquark state. Such a suppression can better be understood in the time-reversed channel,  $q\bar{q} \rightarrow C$ . Indeed, one of the standard decays of a  $q\bar{q}$  state would, for instance, be the creation of an additional  $s\bar{s}$  pair from the vacuum; this would result in the production of a  $K\bar{K}$  pair. By contrast, a  $\phi\pi$  final state is excluded for such a mechanism due to OZI suppression. The mechanism is the same as for baryon pair production in the color flux model suggested in [8]. If the pair  $q\bar{q}$  created from the vacuum has the “wrong” color, *i.e.* different from the parent  $q\bar{q}$  color, it does not completely screen the external color field, and a diquark- antidiquark state is produced. If this state is below threshold for  $B\bar{B}$  production, it can only decay by means of string rearrangement which is

what the C-meson is supposed to do.

The production of a “wrong” color quarks is estimated [8] to be suppressed by an order of magnitude in comparison with a “right” color  $q\bar{q}$  pair. This, however, does not seem enough to explain numerically the dramatic suppression of the  $2\pi$  decay mode of the C-meson.

Another mechanism of C-meson photoproduction which we should discuss briefly is the one originally suggested in [3], *i.e.* the direct transition  $\gamma \rightarrow C$  (fig.4). The vertex of such a transition is unknown, and in [3] it was assumed to be smaller than  $\gamma \rightarrow \rho$  by an order of magnitude. However, a photon can convert directly only to a  $q\bar{q}$  pair, and the subsequent transition from a  $q\bar{q}$  system to the C-meson proves to be suppressed by more than two orders of magnitude, as mentioned above. Thus we estimate the cross section of photoproduction of the C-meson by the mechanism of fig.4 at about 2 – 3 nb. This contribution is negligibly small in comparison with one under consideration in the few GeV energy range. Being independent of energy, however, it can become important at high energies.

It worth mentioning also a last source of background to  $\phi\pi$  photoproduction which comes from the quasielastic production of  $\phi$  accompanied by diffractive dissociation of the target proton to  $p\pi$ . This can be easily estimated. The cross section for elastic photoproduction of  $\phi$  in a few GeV energy range is about 0.4 – 0.5  $\mu\text{b}$  [6]. Diffractive dissociation cross section, for instance  $pp \rightarrow pX$  is about an order of magnitude less than the elastic one in this energy range. Only 1/3 of it goes to  $p\pi^0$ . Assuming factorization, we can estimate the contribution of the term under discussion to about 13 nb. This is quite small as compared with the cross section shown in fig.2. Besides, this background can be substantially reduced with proper geometry of the experiment. Although the cross section of this process is energy independent, its contribution to the mass interval of  $\phi\pi$  under discussion steeply vanishes with energy.

5. *Production of C-meson by kaons:* Since the diquark-antidiquark structure of C-meson supposes a branching ratio  $C \rightarrow K\bar{K}$  about the same as  $C \rightarrow \phi\pi$ , one can consider another process of unsuppressed production of C:  $KN \rightarrow \phi\pi\Lambda$ . The corresponding diagram is shown in fig.5. Assuming that  $\Gamma_{\bar{K}K} \approx 1/2\Gamma_{tot}$ , and  $g_{\pi N\Lambda} \approx g_{\pi NN}$  (according to  $SU_3$ ), we get the cross section of C production shown in fig.6. It proves to be quite large, about 0.1 mb at the maximum which is around 4 – 5 GeV kaon energy.

6. *Conclusions:* The above estimates for the  $C(1480)$  production cross sections by photons and kaons, contain no free parameters. The only assumption made is the diquark-antidiquark structure of the C-meson. Therefore, if an experiment will fail to observe the signal at the predicted level, it will reject the above interpretation of the C-meson, or its existence at all. On the other hand, in the case of a successful

measurement one gets a direct information about branchings of C-decay to  $\phi\pi$  and  $K\bar{K}$ .

In closing, it is interesting that the issue raised in this paper should readily be solved in the forthcoming search at CEBAF in the proposed measurement of rare radiative decays of the  $\phi$  meson, where, with a 4 GeV photon beam of intensity  $5 \times 10^7$  sec a branching ratio sensitivity for  $\phi$  decays of about  $10^{-5}$  is expected [9].

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## Figure Captions.

- Fig. 1. Relevant diagram for C-meson photoproduction.  
Fig. 2. Energy dependence of the C-meson photoproduction cross section.  
Fig. 3. Mass distribution for C-meson photoproduction at  $E_\gamma = 4$  GeV.  
Fig. 4. C-meson photoproduction via direct  $\gamma \rightarrow C$  transition.  
Fig. 5. C-meson production by kaons.  
Fig. 6. Energy dependence of the C-meson cross section for production by kaons.